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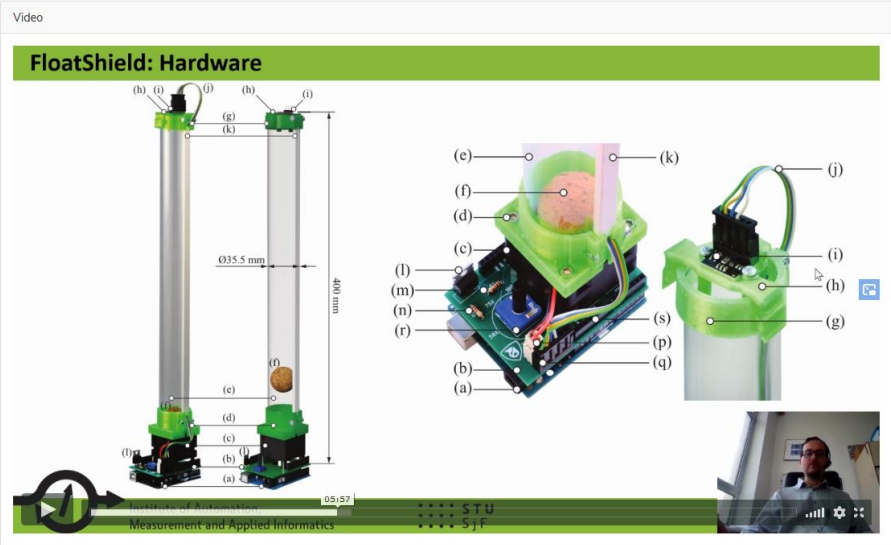
Linking Research Fields with Benchmark Systems – opportunities through the Aerodynamic Floating experiment.

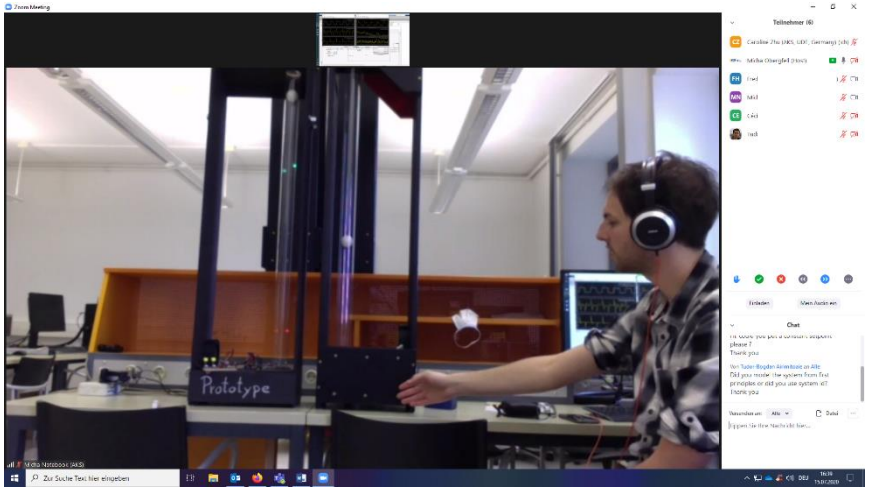
A joint (online) discussion with members of Slovak University of Technology in Bratislava (STU), University of Duisburg-Essen, Germany (UDE, Depart. AKS), and others.

Host: Micha Obergfell (UDE)

Background

- IFAC World Congress 2020 ~~Berlin, Germany~~ → 1st virtual IFAC WC
- Video Presentations and Demonstrator-Sessions in zoom





- „networking through the (world-wide) network“

Guests from STU, some UDE/AKS-members

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- Gergely Takács, Profesor CSc.,PhD. gergely.takacs@stuba.sk
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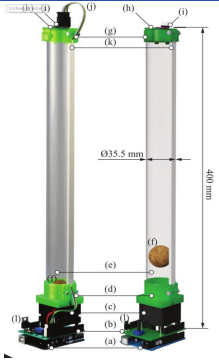
- Birgit Köppen-Seliger, Dr.-Ing., AOR, birgit.koeppen-seliger@uni-due.de
- Chris Louen, Dr.-Ing., AOR, chris.louen@uni-due.de
- Micha Obergfell, PhD-candidate, micha.obergfell@uni-due.de

- Many others

Outline

- Introduction of FloatShield and ALB-plant
- Key design similarities and differences
- First principle model approaches



- Challenges using Benchmark Systems in research
- (Potential) usage in education & research
- Discussion

Introduction of FloatShield and ALB-plant

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FloatShield

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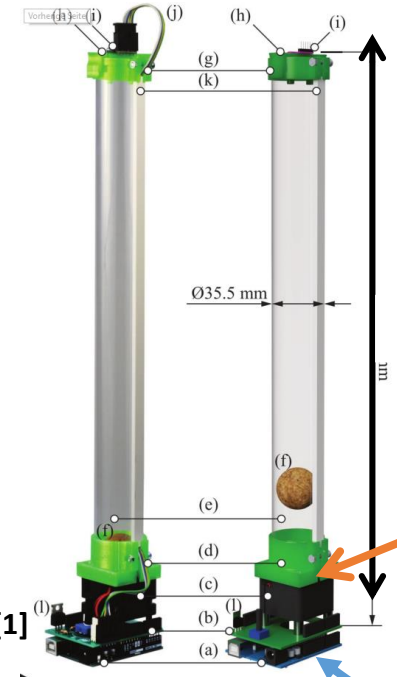

0.4 m

Fan

[1]

Arduino Uno Footprint

Aerodynamic Levitation of a Ball (ALB)

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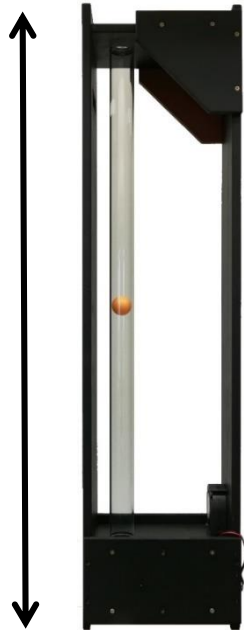
Offen im Denken



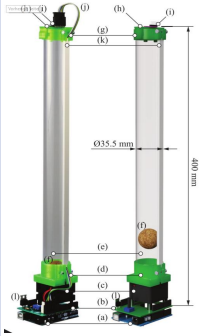
1.2 m

[2]

Valve

Fan

Key design similarities and differences



FloatShield, STU

- Fan (axial)
- Distance Sensor (Laser TOF)
- Arduino Uno (8 Bit, 16 MHz)
- SOA mech. design (3D-print)
- Very cheap (approx. 30 €)

Aerod. Levitation of a Ball (ALB), UDE

- Fan (radial), Valve (Servo)
- Sensors: Distance (Laser TOF), Fan speed, pressure (opt.)
- Arduino Uno (8 Bit, 16 MHz)
  ⇔ Raspberry Pi Zero (32 Bit, 1 GHz)
- Cheap (approx. 150 €)

- Back-Pack compatible design
- Open Source-Environment „Automation Shield“
- Runs with Arduino **or** MATLAB/Simulink

- Pressurized Box for (more) steady flow, valve and housing of components
- Requires Arduino **and** MATLAB/Simulink

ARDUINO

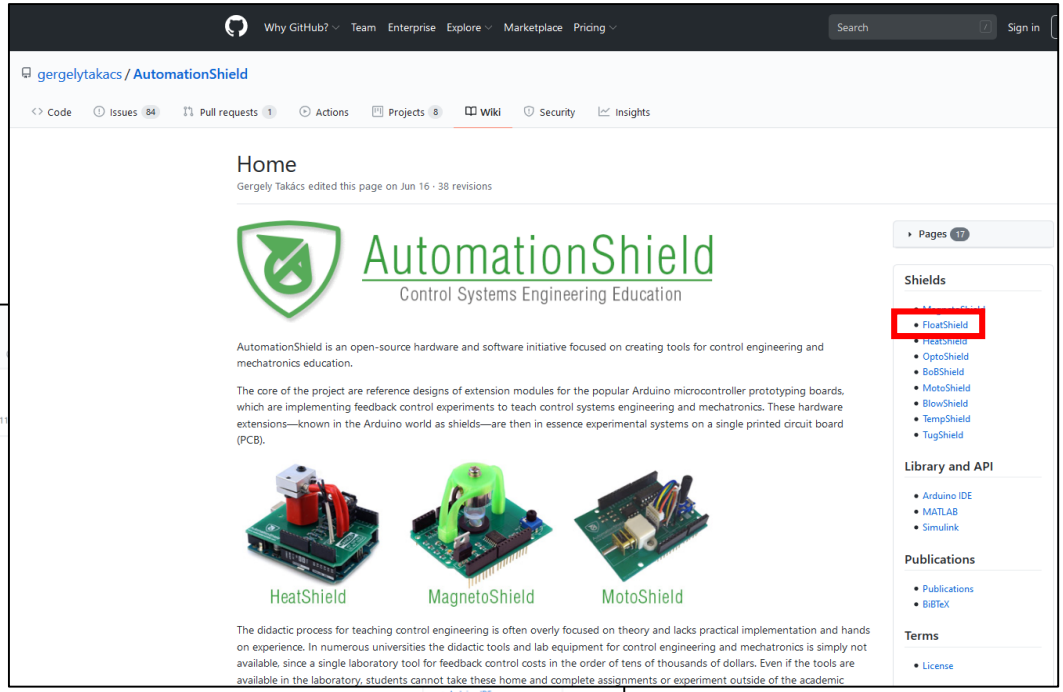
MATLAB & SIMULINK

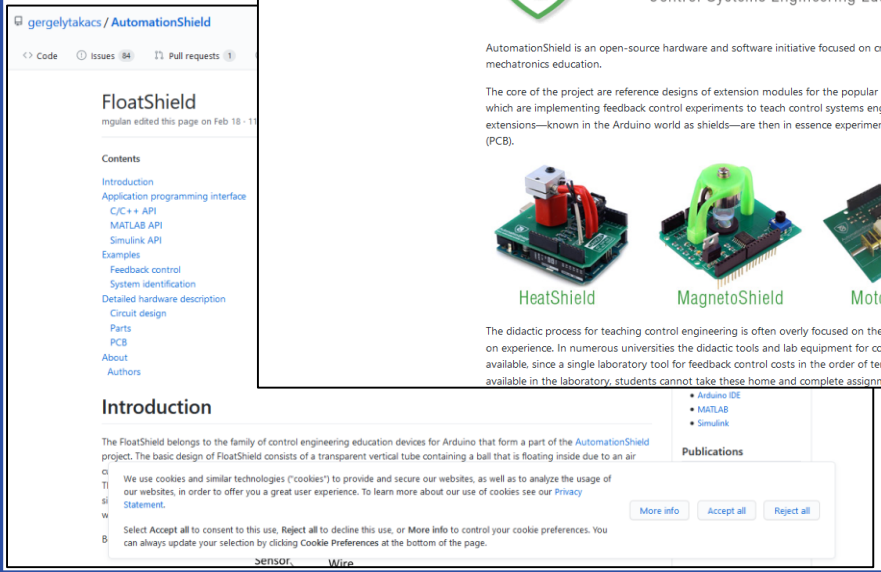
ARDUINO

MATLAB & SIMULINK

www.arduino.cc/en/Trademark/ www.mathworks.com/trademarks/

AutomationShield online on GitHub





- Open source software and design data
- Great documentation
- Community based

- All Based on Arduino Uno, upgrades are possible (!)

- (partially) working with ALB-plant as well

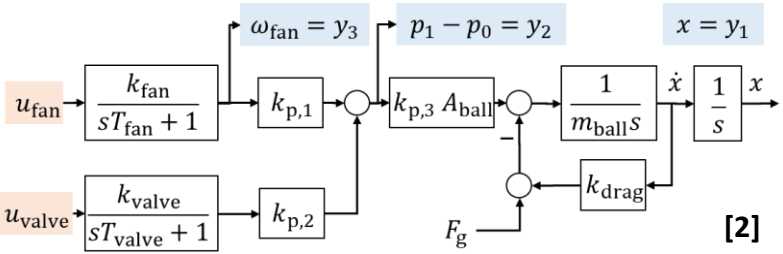
https://github.com/gergelytakacs/AutomationShield/wiki

First principle model approaches

Linearized model structure for both systems:

- PT2 + Integrator

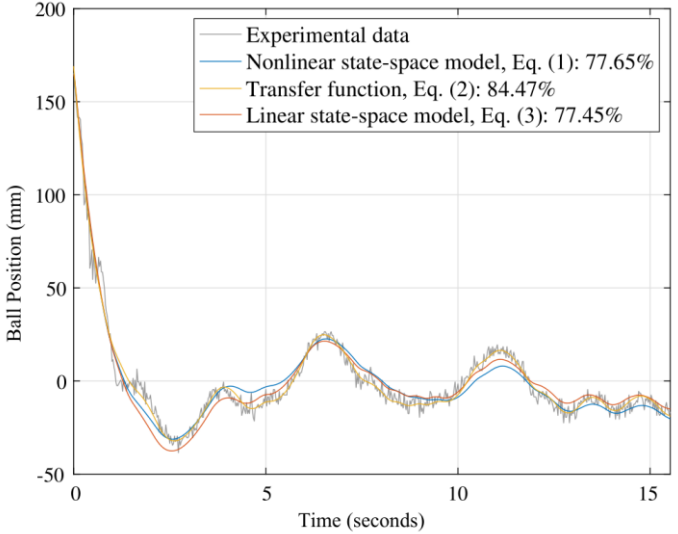
$$\frac{\delta H(s)}{\delta U(s)} = \frac{1}{s(\tau_1 s + 1)(\tau_2 s + 1)},$$



[2]

FloatShield blocks in Simulink:

FloatShield Identification data:



[1]

First principle model approaches

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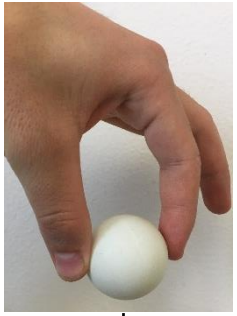
Parameter identification experiments can be performed (safely):



Drop experiment

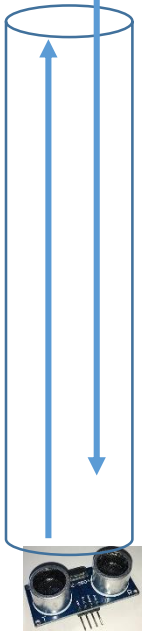
Fan time constant (4-Wire-Fan)

PWM --
Tacho --
+12 --
GND --

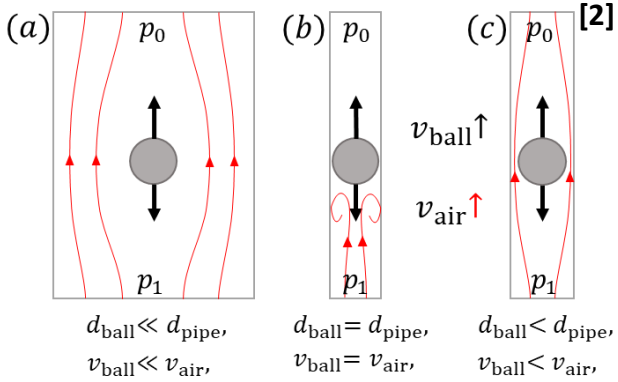
Different Ball weights:

Wind speed measurement: (two ultrasonic sensors, ?)

HC-SR04



$$v_{air} = \frac{l}{t_1 - t_2}$$



[2]

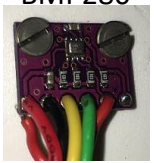
$d_{ball} \ll d_{pipe}$, $v_{ball} \ll v_{air}$,

$d_{ball} = d_{pipe}$, $v_{ball} = v_{air}$,

$d_{ball} < d_{pipe}$, $v_{ball} < v_{air}$,

Pressure Sensor: (differential, abs.)

BMP280



(Potential) usage in education with status quo

- Bachelor/Master Project works
- Bachelor/Master Theses
- Laboratories (Identification, Feedback/Nonlinear Control)
- Linking real and virtual lab experiments (animation) possible

Why?

- Comprehensible but challenging (stability margin)
- Limited number of external influences and states
- Fast Dynamics ($\tau_i < 1\ \mathrm{s}$) + Integrator

→ **But what properties do we need for research?**

Challenges using Benchmark Systems in research

What challenges did you experience?

What are your expectations?

Challenges using Benchmark Systems in research

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Repetition
- duration of measurement series, and (automatic) repetitions

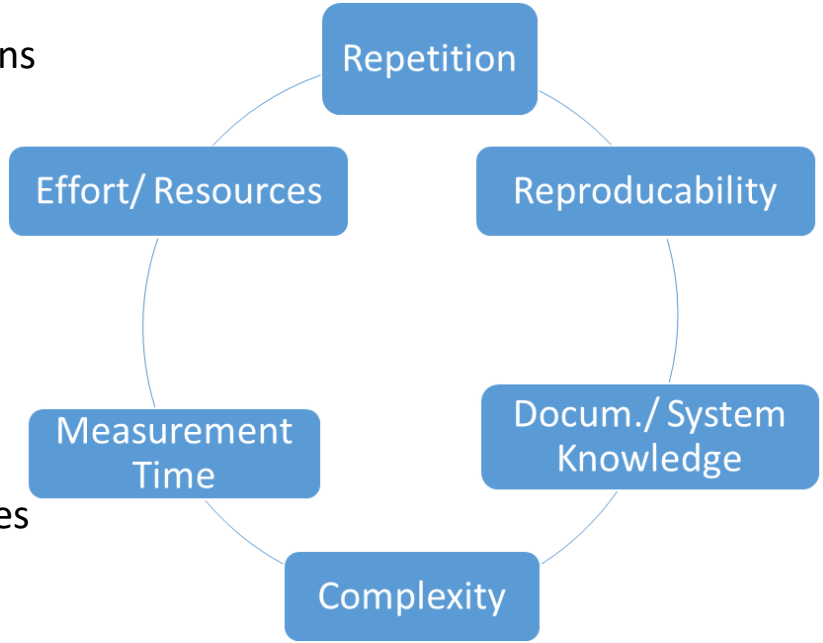
Effort/ Resources
- supervision, (energy) consumption, maintenance

Reproducability
- external/ stochastic influences (short/long term)

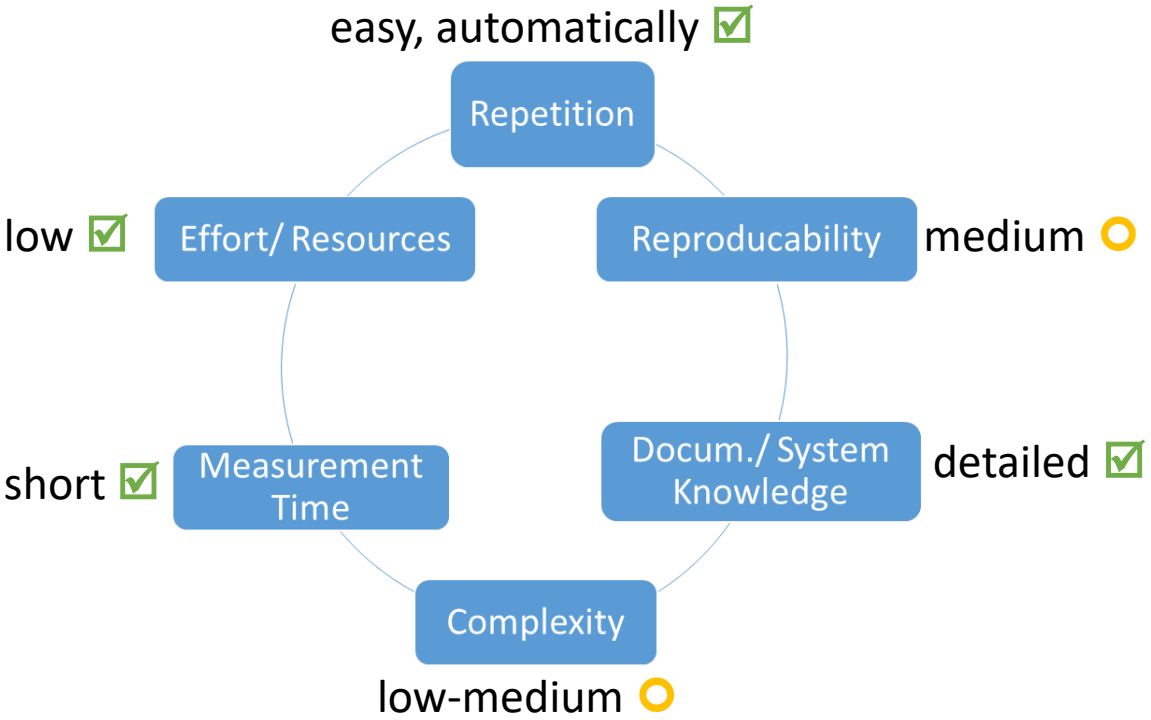
Measurement Time
- required preparation time for a defined measurement series

Documentation/ System Knowledge
- quality, continuous updates

Complexity
- number of proccess variables



The Aerodynamic Floating Benchmark System in research



Usage in research – some ideas

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- Transfer learning/ML:
  - Large number of similar plants possible
  - Safe „learning“ operation
- Performance prediction:
  - Control Performance is crucial
  - Measurements over a (relatively) long time are easy to take (no supervision)
- Nonlinear MPC:
  - System contains weak and strong nonlinearities, safe to test
- Networked/Distributed Control:
  - Access through Matlab/Simulink interface to different channels

Usage in research: Transfer Learning

- How ***similar*** are:
  - System Matrices and Controller gains: $A_i, A_j;\quad K_i, K_j;\quad L_i, L_j;$
  - Closed loop dynamics: $A_i + B_i K_i,\ A_j + B_j K_j;$
  - Systems with „wrong“ controller gain: $A_i + B_i K_i,\ A_j + B_j K_i;$
  - Stable Kernel/Image Representations: $\widehat{M}_i(s), \widehat{N}_i(s);\ \widehat{M}_j(s), \widehat{N}_j(s);$?

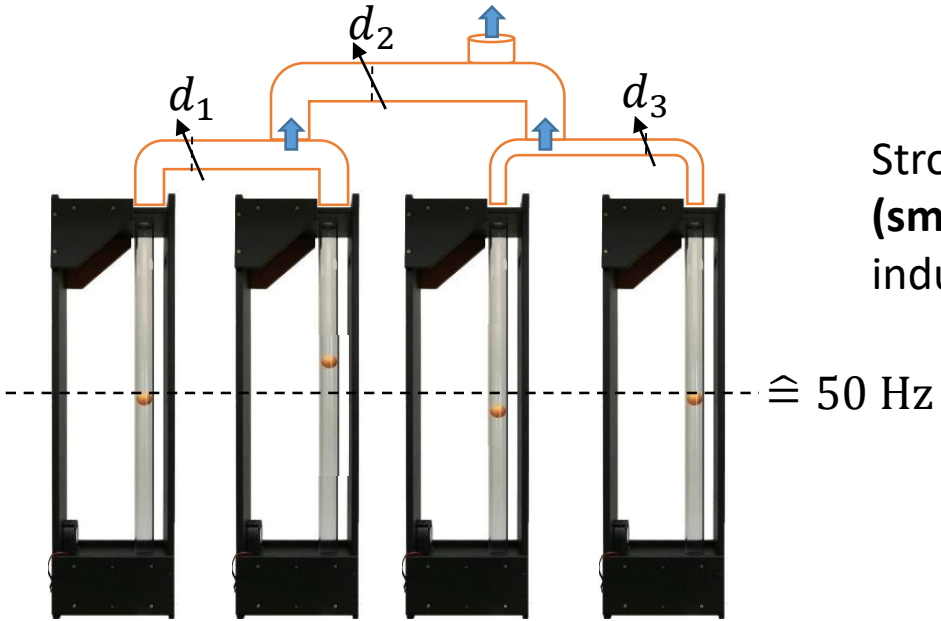
by means of metrics and control performance?

And: How to find & transfer the ***similarity*** properties btw. controllers?

- Differnt parameters can be achieved through: ball weight, diameter, choke, ...
- Large number of similar plants possible

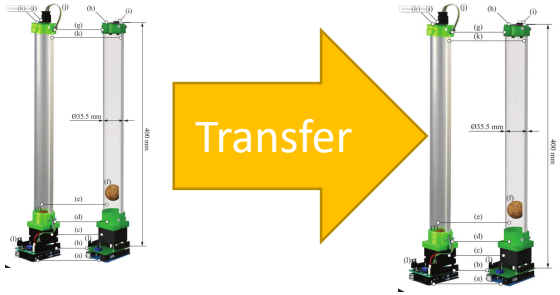
Future extensions for research: Distributed and Networked Control

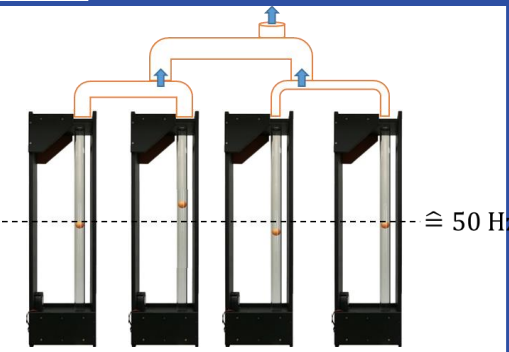
- Create (imbalanced) couplings between different plants/ plant types.

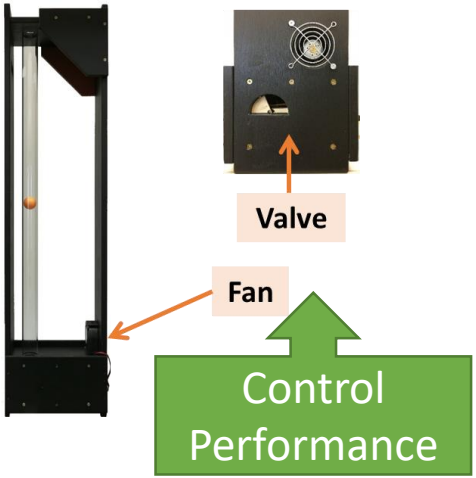


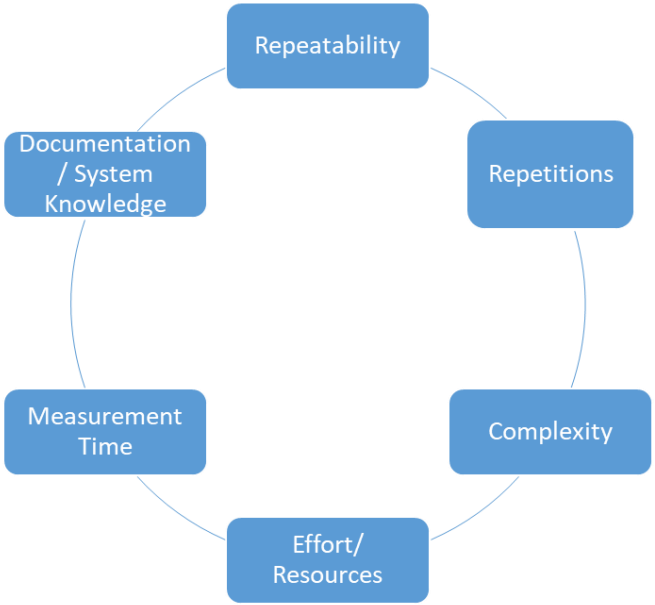
Strong similarities to distributed processes: **(smart) power grid**, water supply, process industry (e.g. gas, steam), ...

Opinions, ideas, discussion ☺

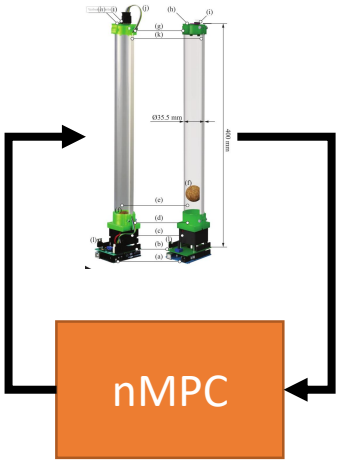








your ideas & remarks



Thank you for your attention and valuable time!

References

- [1] G. Takács, P. Chmurčiak, M. Gulan, E. Mikuláš, J. Kulhánek, G. Penzinger, M. Vdoleček, M. Podbielančík, M. Lučan, P. Šálka and D. Šroba, *FloatShield: An Open Source Air Levitation Device for Control Engineering Education*, **Preprints** of the 20th IFAC World Congress (Virtual), Berlin, Germany, July 12-17, 2020. pp. 17526-17536
- [2] M. S. Obergfell, F. Hesselmann, C. J. Louen and S. X. Ding, *Aerodynamic Levitation of a Ball in a Tube – a Multivariable Experiment Setup*, **Preprints** of the 20th IFAC World Congress (Virtual), Berlin, Germany, July 12-17, 2020. pp. 18010-18013